A Model for Battle Damage Assessment in Command and Control Warfare

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13. ABSTRACT

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The model is constructed using the Design/CPN and Workflow Analyzer software, produced by Meta Software. It consists of a JTF information handling system in a hostile environment. The basis for this model is an Integrated Computer Aided Manufacturing Definition (IDEF0) functional flow diagram of the same system.

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I. INTRODUCTION

A. BACKGROUND

Over 10,000 years ago, wars were fought for land ownership. This period in time is referred to as the era of agricultural wars, where face-to-face combat was the basic method of warfare used. The weapons used were primitive and relied on human brute force to achieve their goals. Orders were given orally and hardly ever in writing.

The industrial revolution brought about another type of warfare. The mass production of goods and materials led to a war of mass destruction. This type of war is referred to as the industrial war or the mechanized war. Weapons were produced to destroy entire regions, societies, and industrial centers.

Nuclear weapons, space assets, advanced computer capabilities and rapidly growing telecommunications have brought about a complex and formidable danger to the warfighter. Today's warfighter is faced with a technological war. Wars are no longer being fought to destroy the land or other physical assets of the enemy, but are fought to destroy the command and control centers, the nerve, of the enemy by means of computer viruses, communications breakdowns and psychological warfare, by means of the media.

1. The Need for Battle Damage Assessment

Battle Damage Assessment (BDA) is the evaluation of damage sustained during an attack. It includes the total number of lives lost, equipment and structural damages and the degradation of information or communications systems. BDA not only is conducted for one's own forces but those of hostile and allied forces affected by the attack. The definition may seem simple, but the processes or methods used for damage assessment are complex. Therefore, improved methods of conducting BDA are required to keep up with the rapidly changing face of war.

Distorted assessments continue to be a major problem for the men in the field, not to mention the commander trying to get a timely and accurate picture of the battle being fought. The commander must rely heavily upon the timely information given to him by those inspecting the battlefield. The importance of accurate BDA during Operation Desert Storm was noted by General Schwarzkopf:

> ...too much optimism could prompt us to launch the ground war too soon, at the cost of many lives; too much pessimism could cause us to sit wringing our hands and moaning that the enemy was still too strong. [Ref. 1:p. 499]

2. Traditional Methods of BDA

During both eras of agricultural and industrial wars, BDA was conducted by physical site inspections. The damage was then estimated by the obvious visible damage to equipment, land and structures. The damage assessment was often slow and inaccurate.

Modern warfare, an electronic warfare, has moved the battle from the land to the heart of the command and control center, its communications links and computers. Today, the commanders out in the field can no longer rely upon those physical inspections conducted because computer viruses are being utilized by both hostile and friendly forces as a weapon to "take out" the opposition's command and control.

> Viruses may be introduced into the computer through a variety of vehicles, ranging from access to a corrupt network to, potentially, infection from a clandestine computer chip on an expansion card or other peripherals. [Ref. 2:p. 19]

B. OVERVIEW OF COMMAND AND CONTROL WARFARE (C^2W)

The definition of Command and Control Warfare (C^2W) used by the Chairman of the Joint Chiefs of Staff is as follows:

> Command and Control Warfare: The integrated use of operations security (OPSEC), military deception, psychological operations (PSYOP), electronic warfare (EW) and physical destruction, mutually supported by intelligence, to deny information to, influence, degrade or destroy adversary C^2 capabilities, while protecting friendly C^2 capabilities against such actions. [Ref. 3:p. 2]

The strategies and techniques of conducting C^2W have changed with the times. Prior to the publication of the Memorandum of Policy No. 30 [Ref. 3], C^2W was referred to as Command, Control, and Communication Countermeasures (C^3M). C^2W now focuses more on how wars are being fought and supports all three levels of conflict: strategic, operational and tactical.

C^2W incorporates two elements: Counter-C^2 and C^2 Protection. Both elements implement five tools (or methods) which support each other. These tools are: OPSEC, military

deception, PSYOP, EW, and physical destruction. A successful C^2W strategy is the integration of the five tools throughout the planning, execution, and termination cycle of any operation.

Counter-C^2 is defined as:

> ...to prevent effective C^2 of adversary forces by denying information to, influencing, degrading or destroying the adversary C^2 system. [Ref. 3:p. 2]

The following is the definition of C^2 Protection:

> ...to maintain effective C^2 of won forces by turning to friendly advantage or negating adversary effort to, influence, degrade, or destroy the friendly C^2. [Ref. 3,p. 2]

A quote from Mao Tse-Tung could summarize the importance of command and control warfare. It is as follows:

> To achieve victory we must as far as possible make the enemy blind and deaf by sealing his eyes and ears, and drive his commanders to distraction by creating confusion in their minds. [Ref. 4, p. 89]

His reference to the "eyes and ears" of the enemy is essentially the command and control center. Creating confusion can be achieved by the implementation of the five tools of C^2W previously mentioned.

C. PURPOSE

The scope of this thesis is to build a dynamic model of a command and control system and to determine the effects of C^2W on that system. The model designed for the experiment is a prototype for battle damage assessment in C^2W. The effects of C^2W are modeled by manipulating various functions and activities of the model.

The foundation for this prototype is the ANSER model. The ANSER model is a process model of the command and control information needs of a "generic" Joint Task Force Commander (JTFC). The main objective of the model is to focus on a set of functions or activities and determine their relationship with the Corporate Information Management (CIM) methodologies.

II. THE MODEL

A. THE ANSER MODEL

Corporate Information Management (CIM) is a process model which focuses on the management methods used within the Department of Defense. CIM is a dynamic model used to simulate the flow of resources through various processes. It is used to uncover any bottlenecks or any idle resources within a system. It could also be used to establish interactions, cost and resource consumption within a system.

The ANSER model is a result of the Joint Staff's efforts to create a process model using the CIM methodologies. The main focus of the ANSER model is to simulate the command and control needs of the Joint Task Force Commander (JTFC). The JTFC may utilize such a model to ensure that the system is being used efficiently. It is a useful decisionmaking tool to the commander, for he can see the problem areas in his system.

B. THE C^2 LOOP

1. Department of Defense Definition of Command and Control

The Department of Defense (DOD) defines command and control (C^2) as:

> The exercise of authority and direction by a purposely designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures

employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. [Ref. 5:pp. 77]

This definition separates C^2 into a collection of functions and the systems of people, procedures, and equipment that support command. This study first looks at how to model the functions of C^2 and then adds the systems that support these functions.

2. Lawson's C^2 Process

Fundamentally there is very little difference be-tween the C^2 system used by most forces in World War II and a modern one found anywhere in the world today. In fact a gen-eric model of C^2, such as the one proposed by Joel S. Lawson, would probably be as applicable to the system used by Alexander the Great as it would to that of General Schwarzkopf.

The Lawson model (Figure 1) uses five functions to encompass all of the activities that take place within a C^2 system. These five functions are: *sense, process, compare, decide,* and *act*. The *sense* function gathers data on the environment in which the C^2 system exists--including friendly, allied, and hostile forces, terrain, weather, political happenings, and so on. The *process* function groups this data together, correlates it, and then filters it to provide the commander with useful information about the environment. The *compare* function compares and contrasts the existing state of the environment--the relative strengths,

weaknesses, positions, etc.--with the desired state, the commander's view of what the state of the environment should be. The *decide* function chooses among the available courses of action for reconciling the two states. Finally the *act* function translates the decision into action.

3. Using Lawson's Model

Superimposing Lawson's model onto the Anser model of a Joint Task Force (JTF) [Ref. 6:pp. 5-55] resulted in the separation of the five functions into two categories: those internal to the JTF and those external. The functions internal to the JTF are *process, compare,* and *decide,* while *sense* and *act* are

external. It may be argued that both *sense* and *act* are also internal to the JTF; however, as the focus of this study is the information flow internal to the JTF and neither of these functions are an integral part of that flow, they may be safely categorized as external.

C. THE IDEF0 MODEL

The next step in this study was to create a model of the activities involved in each function using the Integrated Computer Aided Manufacturing Definition (IDEF) standard for describing systems. The activities listed in the Anser model will be assigned to the three internal functions and then converted to an IDEF0 model.

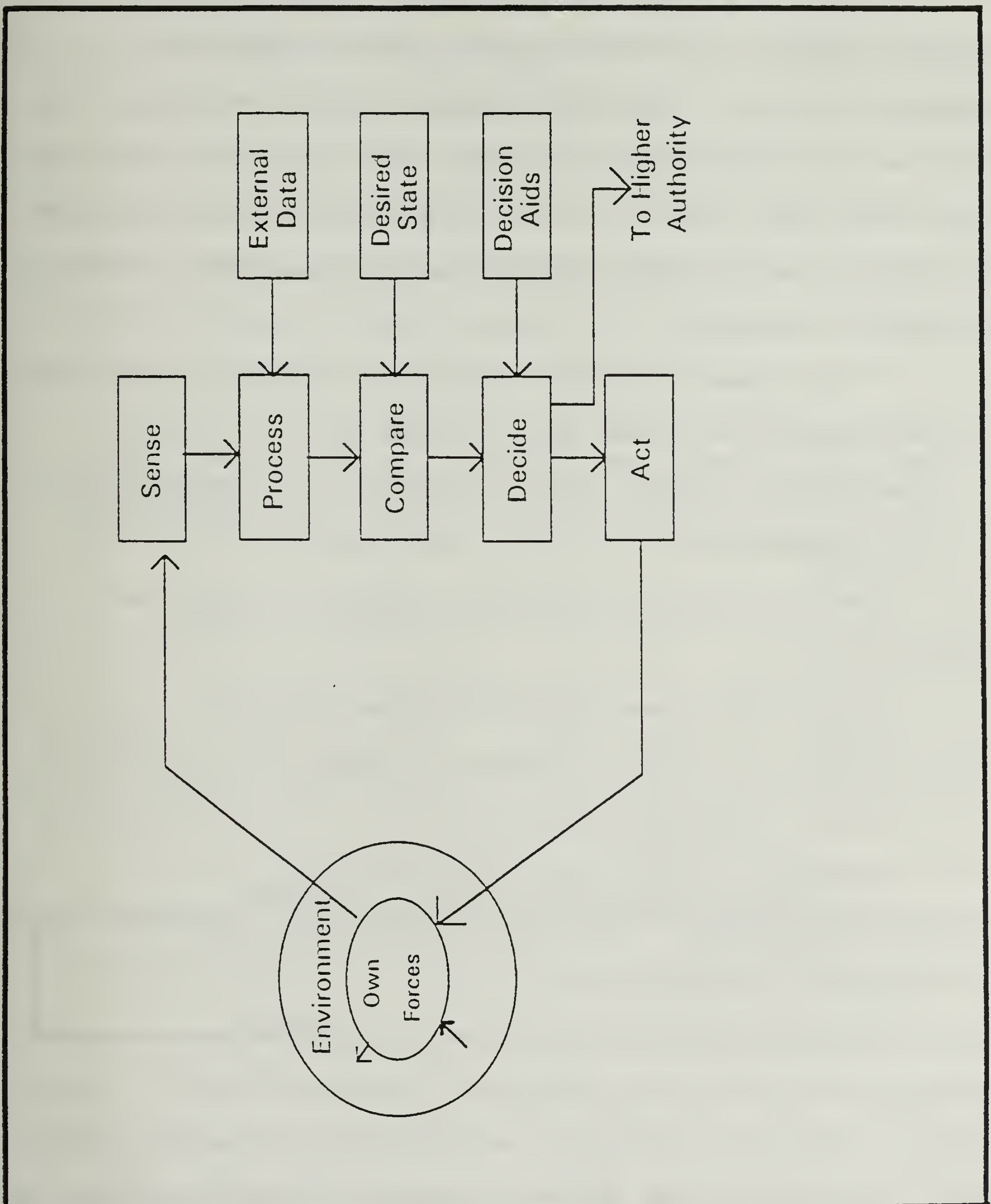


Figure 1: Lawson's Model of the C^2 Process [Ref. 7:p. 32]

1. An Overview of IDEF0

IDEF0 is a graphical portrayal of the processes within an organization. It shows the logical interdependencies of various activities but says nothing about the time flow. Hence one can determine the functions that deal with each other, the order they do it in, and what is needed by each, but nothing can be determined about how long each takes to perform its activity.

There are seven definitions essential to an understanding of an IDEF0 model. They are:

1. Activity - named process, function, or task having one or more occurrences;
2. ICOM - an acronym for Input, Control, Output, and Mechanism;
3. Input - resources consumed by the activity;
4. Control - activity blueprints, plans or directives;
5. Output - activity products;
6. Mechanism - tools used in an activity;
7. Decomposition - the breaking down of an activity into its component subactivities

Using the above definitions, any organization can be decomposed into its component activities with inputs, controls, outputs, and mechanisms required for each activity. Thus a detailed, **but static**, graphical representation is created. This was already accomplished by Anser for the JTF so that all that remained of this step in the study was to

assign activities to C^2 functions.

2. IDEF0 Model of the C^2 Loop

In their report, Anser decomposed the JTF as far as four levels below the top level diagram. It was necessary to determine which of the activities and on which levels to assign to each function of the C^2 loop. This required a careful reading of the activity definitions in order to perform the appropriate matching. As an example, here is the definition for activity A113 - Evaluate Impact:

> The process of evaluating the impact of identified significant events within their environment and assessing the current and future effect in light of the National Security Strategy, CINC's Theater Strategy and Objectives, and the JTF's Operational Objectives and mission.
> [Ref.6:p. B-2]

Careful examination of this definition clearly shows it to be part of the *process* function. Therefore, it was assigned to that function. Table 1 shows an example of the matrix constructed from matching the activities and functions. The entire matrix is contained in Appendix A.

Table 1: EXAMPLE ASSIGNMENT MATRIX

Function	Activities
Process	A111, A112, A113

A careful comparison of the assignment matrix and the ANSER model will show that all activities after A51 were excluded. The basis for this was the categorization of those activities as belonging to the *act* function and hence not germane to this study. Again, the argument could be made that

since the JTF has forces, the activities which govern their employment should be included in the study. However, though information handling does take place within these activities, they are not a basic part of the JTF information handling system.

This is a good point to discuss the measure of effectiveness (MOE) chosen for the study. Since the Commander, Joint Task Force (CJTF) Execute Order is the last link in the internal information handling chain and it is the method by which the CJTF activates the forces involved, it was determined that the time necessary to produce the Execute Order was the best MOE. The assumption made for this MOE is that the order will take longer to produce if the C^2 loop has been degraded.

At this point the IDEF0 model was constructed using Design/IDEF, a program created by Meta Software Corporation. This provided a static model of the JTF information system; however, it did not allow study of the behavioral characteristics of the system. For that, a tool for dynamic representation of the system was needed. Petri nets filled that need.

D. THE COLORED PETRI NET (CPN) MODEL

1. An Overview of CPN

A Petri net is a tool for the study of systems. Essentially it is a mathematical representation (model) of the system to be studied. Analysis of the net can provide

information on the structure and behavior of the modeled system.

Any Petri net has five primitive components: tokens, places, transitions, inputs, and outputs. A token is an object used to define execution of the Petri net. For this study a "packet" of information was used. A place is a location tokens are assigned to (or reside in). Transitions equate to activities, processes, or functions. The "firing" of transitions moves tokens, while the arrival of tokens enables the firing of transitions. Inputs and outputs are functions that map either a transition to a set of places or a place to a set of transitions.

The structure of a Petri net is of the form $C = (P,T,I,O)$, where:

1. C = the Petri net structure
2. P = the set of places
3. T = the set of transitions
4. I = the input functions
5. O = the output functions.

These are the "rules" for the mathematical representation of the system. The structure of a fairly simple system is shown below:

$C = (P,T,I,O)$

$P = \{p_1,p_2,p_3,p_4\}$

$T = \{t_1,t_2\}$

$I(t_1) = \{p_1\}$ $\qquad$ $O(t_1) = \{p_2,p_3\}$

$I(t_2) = \{p_2, p_3\}$ $O(t_2) = \{p_4\}$.

The structure of a Petri net is necessary, but a visual representation of the system is often more useful. For visual representation there is the Petri net graph, which is nothing more than a graphical representation of the structure. Figure 2 is a Petri net graph of the structure used earlier. Note that it is easy to follow and gives at a glance all the information it contains. For this reason most applied work is done using the graph while most theoretical work is done using the structure.

Marking takes the Petri net one step further by assigning tokens to places. This step provides a snapshot of the model at a given moment. Figure 3 is the marked version of the Petri net used before. The format for the marked Petri net is $M = (C,u)$, where:

M = the marked Petri net

C = the Petri net structure

u = a function mapping the set of places, P, to the non-negative integers N.

Hence, the marked Petri net in Figure 3 would be:

$M = (C,u)$

$C = (P,T,I,O)$ $u = (1,2,0,0)$

$P = \{p_1, p_2, p_3, p_4\}$

$T = \{t_1, t_2\}$

$I(t_1) = \{p_1\}$ $O(t_1) = \{p_2, p_3\}$

$I(t_2) = \{p_2, p_3\}$ $O(t_2) = \{p_4\}$.

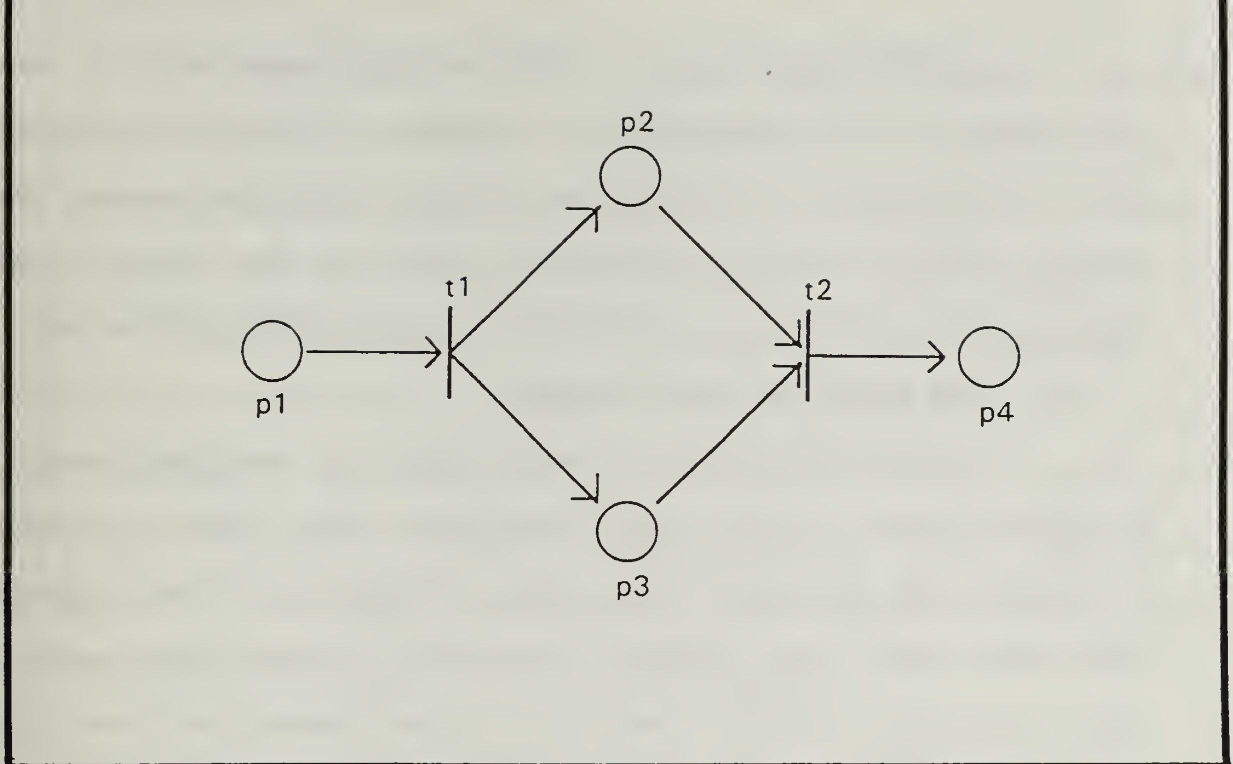


Figure 2: Petri Net Graph

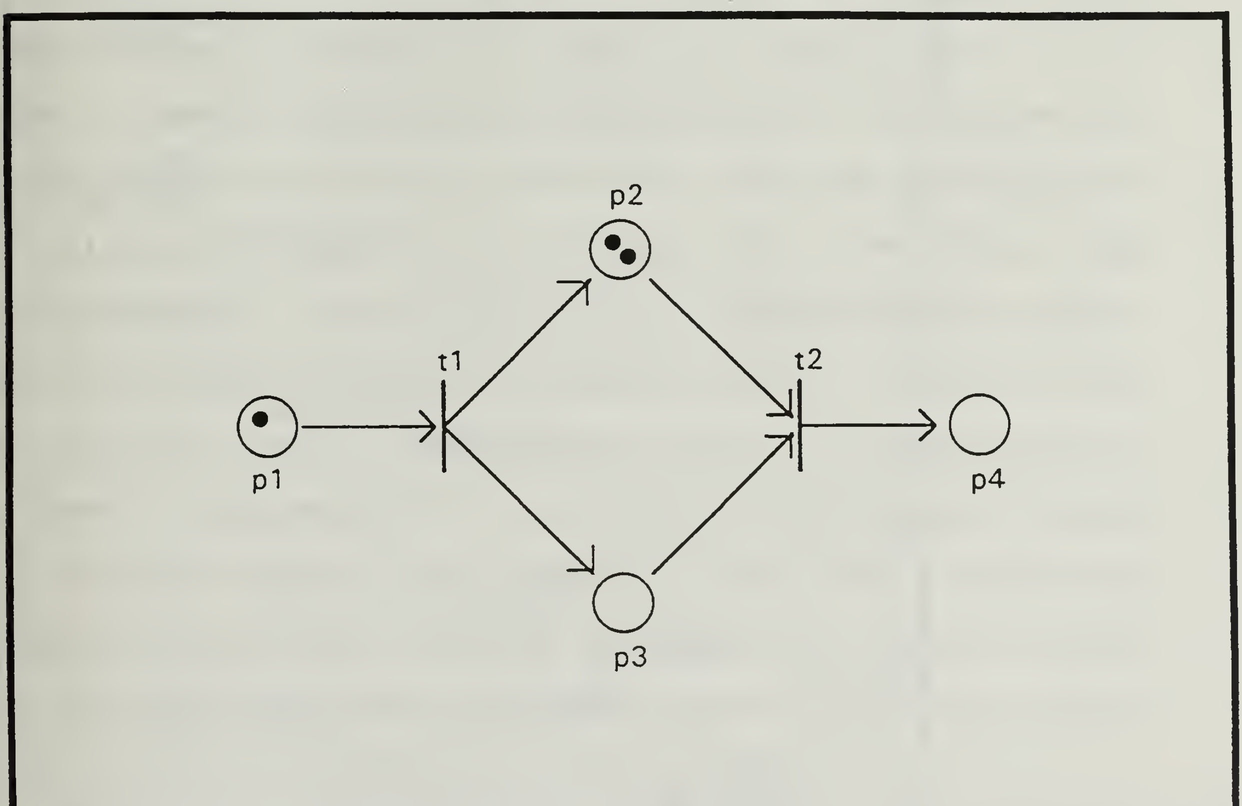


Figure 3: Marked Petri Net

A marked Petri net looks good but says nothing about the tokens or the purpose of the model. To be of any real use, the information must be associated with the tokens. When this is done, a colored Petri net (CPN) is the result. This was the next step to be performed on the ANSER JTF model.

2. CPN Model of the C^2 Loop

To come up with a useful model it was necessary to determine what a token would represent, what time unit would be used, the duration of each activity, and any special considerations for modeling specific situations, such as indecisiveness and C^2W. Early on it was determined that since the focus of the study was the information system, the token should represent a "packet" of information that would appear to be sufficient to make a decision under normal circumstances. It was decided that in order to keep the model as flexible as possible, the time unit would not be specified. Thus the distance from headquarters and the availability of communications systems can both be modeled, or ignored, with equal facility. The assignment of activity durations were straightforward. Using Design/IDEF, each activity was arbitrarily assigned a duration of one time unit. Then the activities within each C^2 function were lumped together into a black box and the durations summed. This sum was assigned to the black box of each function as its total duration.

The decision on how to model indecisiveness and C^2W was driven by the software. The assignment of probabilities to specific paths (outputs) along with the creation of dummy activities was the method used to model indecisiveness and C^2W. For indecisiveness, a 0.80 probability was assigned to the output to the next black box while a probability of 0.20 was assigned to the output of a dummy activity with a duration equal in value to the activity from which the output came from (Figure 4). Modeling C^2W required a more complicated form and is discussed in detail in the next section.

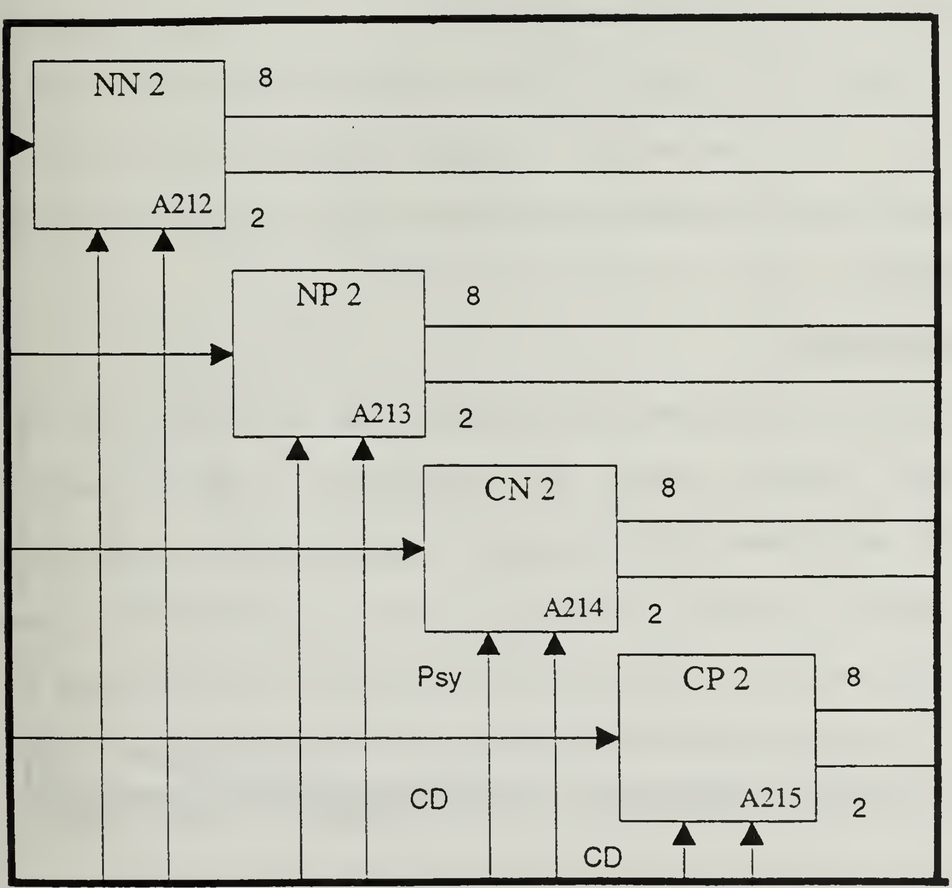


Figure 4: Model for Indecisiveness

E. MODELING C^2 WARFARE

1. Categories of Attacks

The definition of C^2W decomposes into three basic categories for modeling purposes. They are:

1. Attacks against the information before the system receives it;

2. Attacks against the systems that process or move the information; and

3. Attacks against the personnel handling the information and making decisions using it.

While each type of attack is different, the effect of each is to degrade or destroy the overall systems's capability to turn information into a usable product (an execute order in this case). Since the focus is on the effects (as opposed to the details of the methods) of the attack, modeling the effects of each can be done using many of the same techniques for all of them.

2. Methodology

The basic building blocks used in modeling C^2W were the same as those used in modeling indecisiveness; probabilities and dummy activities. First each activity was decomposed into a main activity and a series of dummy activities (Figure 5). Probabilities were then assigned to each output to reflect the uncertainty of success of an attack of a specific type. The basic probabilities were 0.80 to proceed with processing and 0.20 to seek more information.

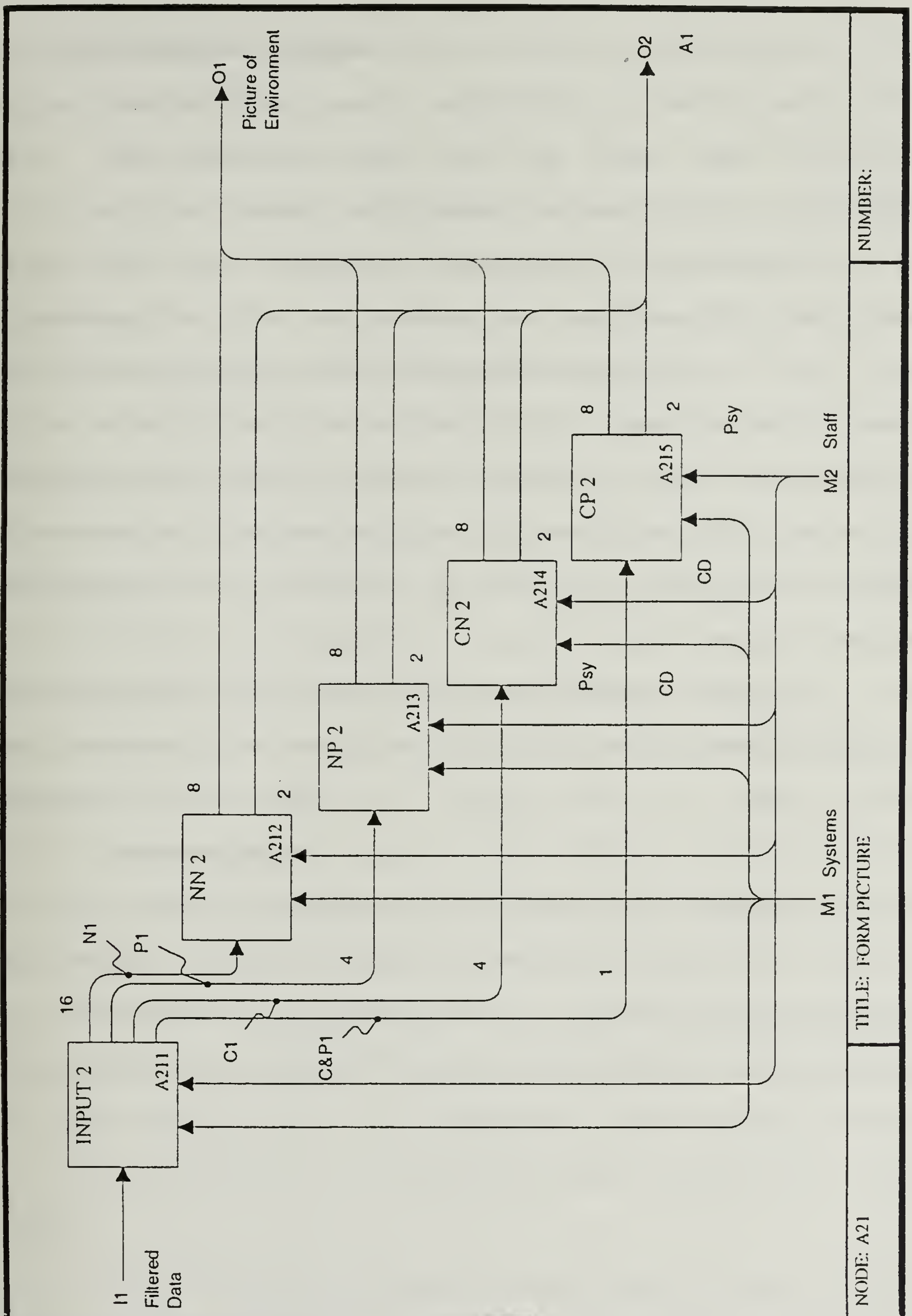


Figure 5: Modeling C^2W

As it was possible to have more than one attack at a time, there were probability products. These products were reduced so their sum would be 25, thus ensuring that enough differences would show up during the simulation runs.

The next step in construction of the model was the assignment of subtypes of mechanisms to the appropriate activities. This assignment would allow manipulation of the speed of processing. Specifically, subtype DA (Data Attack) was used for attacks against incoming information, subtype CD (C^3 Degradation) was used for attacks against the systems and subtype PSY (psyops) was used for attacks directed against the personnel involved.

To model attacks against information it was necessary to add a dummy activity to the front end of the model whose function was to either accept or reject the information received. When attacks are present, the speed factor of the system subtype "DA", which is assigned to the activity, confirms that data is increased (that is, it will take longer to perform the activity). If the simulator determines, using the assigned probabilities, that the attack was successful, then the extra time is accrued.

F. EXPERIMENTAL DESIGN

1. Setup

This model was built and run using a set of software produced by Meta Software Corporation: Design/IDEF, Design/CPN, and Work Flow Analyzer. Two Macintosh IIci computers with 70Mb of RAM were used as the platforms for the experiment, each running Design/CPN System 7.

Due to the limited RAM of the computers only ten runs of the model could be made for each cycle of the simulator. Additionally, the limited RAM also excluded use of the Excel spreadsheet as an output. As a result, each cycle required initializing the simulator, running the model, manually extracting the data, and clearing the report. Finally, at the end of five cycles, the levels of each of the factors would be adjusted as required.

2. Assumptions

Certain assumptions were made to enable the use of this model. Theses assumptions were:

1. No action can be taken by JTF forces without orders;
2. Orders are issued only when sufficient information is available; and
3. The CJTF will try to get sufficient information to issue orders.

The following assumptions were made in order to allow analysis of the data:

1. All samples are random samples from their respective

populations;

2. There is mutual independence among the various samples; and

3. Distributions are assumed to be identical.

3. Statistical Design

To ensure the assumption of normality was valid, 50 runs were made for each configuration. There were three factors (data attack, C^3 degradation, and psyops) at two levels (1 or 2) for a total of eight configurations. A balanced, multifactor ANOVA was made on the data.

4. Hypotheses

Seven null hypotheses were formulated to test the model. They are as follows:

1. Information Attacks

   Information attacks have no effect on the time needed to produce the CJTF Execute Order.

2. C^3 Degradation

   C^3 degradation has no effect on the time needed to produce the CJTF Execute Order.

3. Psyops

   Psyops have no effect on the time needed to produce the CJTF Execute Order.

4. Information Attacks And C^3 Degradation

   There is no interaction between information attacks and C^3 degradation.

5. Information Attacks And Psyops

   There is no interaction between information attacks and psyops.

6. C^3 Degradation And Psyops

   There is no interaction between C^3 degradation and psyops.

7. Information Attacks, C^3 Degradation And Psyops

   There is no interaction between all three factors together.

The alternate hypotheses are the converses of each null hypothesis.

III. SIMULATION RUNS

A. RESULTS OF THE SIMULATION RUNS

After each cycle of the simulator, the time to produce the execute order was transferred from the Excel-ready output form, used by Work Flow Analyzer, to a data collection worksheet. From there the data was transferred to a Minitab worksheet in a form that would allow a balanced, multi-factor Analysis of Variance (ANOVA) of the data. The three factors and the output of the model were each assigned a column, while each row of the worksheet represented one run of the model. Then the levels one and two were assigned to each factor, according to the speed factor assigned to the appropriate mechanism subtype for that run. This is shown in Figure 6. For example row one of Table 2 would translate as:
DA speed = 1.0, CD speed = 1.0, and PSY speed = 1.0, resulting in TIME (to produce execute order) = 45.

Table 2: EXCERPT FORM MINITAB WORKSHEET

	C1 DA	C2 CD	C3 PSY	C4 TIME
1	1	1	1	45
2	1	1	1	82
3	1	1	1	52
4	1	1	1	45
5	1	1	1	80
6	1	1	1	45
7	1	1	1	45
8	1	1	1	50
9	1	1	1	48
10	1	1	1	45

The next step was to analyze the data from the runs. Given the hypotheses that were being tested, the first form of the ANOVA test was DA*CD*PSY, an interaction between all three factors. The values of interest were the p-values for each factor and cross-products, as these would indicate the lowest value for which a given hypothesis could be rejected. The results of the first ANOVA are shown below in Tables 3 and 4.

Table 3: FIRST ANOVA TEST INPUTS

FACTOR	TYPE	LEVELS	VALUES
DA	fixed	2	1 2
CD	fixed	2	1 2
PSY	fixed	2	1 2

Table 4: FIRST ANOVA TEST RESULTS

SOURCE	DF	SS	MS	F	P
DA	1	65869	65869	55.24	0.000
CD	1	82398	82398	69.10	0.000
PSY	1	104039	104039	87.25	0.000
DA*CD	1	63	63	0.05	0.818
DA*PSY	1	9264	9264	7.77	0.006
CD*PSY	1	1541	1541	1.29	0.256
DA*CD* PSY	1	44	44	0.04	0.847
ERROR	392	467443	1192		
TOTAL	399	730661			

The factors that appeared to be significant at this point were DA, CD, PSY, and DA*PSY. The p-value for each was low enough to virtually assure rejection of the associated hypotheses. Further testing was required to ensure that each factor was truly significant. The second ANOVA test was of the form DA*PSY and the results are shown in Tables 5 and 6.

Table 5: SECOND ANOVA TEST INPUTS

FACTOR	TYPE	LEVELS	VALUES
DA	fixed	2	1 2
PSY	fixed	2	1 2

Table 6: SECOND ANOVA TEST RESULTS

SOURCE	DF	SS	MS	F	P
DA	1	65869	65869	47.30	0.000
PSY	1	104039	104039	74.71	0.000
DA*PSY	1	9264	9264	6.65	0.010
ERROR	396	551489	1393		
TOTAL	399	730661			

Once again DA and PSY appeared clearly to be significant as their p-values remained 0 (zero). On the other hand there was a slight increase in the p-value for DA*PSY. Nonetheless, it was considered significant as a value of 0.01 is usually the lowest used, and the hypothesis can be rejected for any value equal to or greater than that. The only test remaining was of each factor taken alone, the results of which are shown in Tables 7 and 8.

Table 7: THIRD ANOVA TEST INPUTS

FACTOR	TYPE	LEVELS	VALUES
DA	fixed	2	1 2
CD	fixed	2	1 2
PSY	fixed	2	1 2

Table 8: THIRD ANOVA TEST RESULTS

SOURCE	DF	SS	MS	F	P
DA	1	65869	65869	54.53	0.000
CD	1	82398	62398	68.21	0.000
PSY	1	104039	104039	86.13	0.000
ERROR	396	478355	1208		
TOTAL	399	730661			

It was now clear that all three factors were significant by themselves as was the interaction of DA and PSY. It was then possible to decide whether or not to reject the hypotheses previously stated. Based on the above results obtained, the following decisions were made:

1. Information Attacks

   Attacks against the data have no effect on the time required to produce the CJTF Execute Order. Therefore, the hypothesis is rejected. Clearly data attacks did affect the production time as witnessed by the p-value for that factor.

2. C^3 Degradation

   C^3 degradation has no effect on the time required to produce the CJTF Execute Order. Therefore, the hypothesis is rejected. CD is clearly a significant factor based on the ANOVA tests.

3. Psyops

   Psyops have no effect on the time required to produce the CJTF Execute Order. Therefore, the hypothesis is rejected. Like DA and CD, PSY is clearly a significant factor.

4. Information Attacks And C^3 Degradation

   There is no interaction between data attacks and C^3 degradation. Therefore, the hypothesis is NOT rejected. The ANOVA tests clearly show that DA*CD is not a significant factor.

5. Information Attacks And Psyops

There is no interaction between data attacks and psyops. Therefore, the hypothesis is rejected. The ANOVA test shows that for values greater than or equal to 0.01 this was a significant factor.

6. C^3 Degradation And Psyops

There is no interaction between C^3 degradation and psyops. Therefore, the hypothesis is NOT rejected. CD*PSY had much too high of a p-value to consider it significant.

7. Information Attacks, C^3 Degradation, And Psyops

There is no interaction between data attacks, C^3 degradation, and psyops. Therefore, the hypothesis is NOT rejected. Like CD*PSY, the p-value here is too high to conclude that this cross was significant.

The rejection of four of the hypotheses yielded information necessary to the verification of the experiment's design. Their relation to the model then was the next step in the study.

B. VARIATIONS OF THE MODEL

1. First Variation

The first variation attempted for this study involved changing the probabilities used at the outputs of the activities that determine whether an attack of a specific type is successful or not. In the original model, the basic

probability of success for an attack was 0.20 and the probability of an unsuccessful attack was 0.80. In this variation, the probabilities were changed to 0.30 and 0.00 respectively and then all probability products were recomputed (the actual numbers assigned were 5, 2, 2, and 1). What difference would this make as far as the analysis and the hypotheses? This was the question to be verified based on the data shown in Tables 9 and 10 for the DA*CD*PSY ANOVA.

Table 9: DA*CD*PSY ANOVA TEST INPUTS

FACTOR	TYPE	LEVELS	VALUES
DA	fixed	2	1 2
CA	fixed	2	1 2
PSY	fixed	2	1 2

Table 10: DA*CD*PSY ANOVA TEST RESULTS

SOURCE	DF	SS	MS	F	P
DA	1	118267	118267	101.00	0.000
CD	1	111957	111957	95.61	0.000
PSY	1	260917	260917	222.83	0.000
DA*CD	1	14448	14448	12.34	0.000
DA*PSY	1	243	243	0.21	0.649
CD*PSY	1	31791	31791	27.15	0.000
DA*CD* PSY	1	5761	5761	4.92	0.027
ERROR	392	459000	1171		
TOTAL	399	1002384			

There were some differences noted. DA*CD and CD*PSY were shown to be significant, and the three-way interaction was significant for a p-value greater than or equal to 0.027 (the commonly used p-value is 0.05). These results led to the rejection of all but one hypothesis. The only one not rejected is that there is no interaction between data attacks and psyops.

It was clear that changing the output probabilities would influence the significance of the interactions. Would changing the probabilities used to model indecisiveness have a similar effect? This was the next question to be verified.

2. Second Variation

The output probabilities were returned to 0.20 and 0.80 while the probabilities used for indecisiveness were changed to 0.90 for the go-ahead and 0.10 to get more information. The results of the DA*CD*PSY ANOVA are shown in Tables 11 and 12.

Table 11: DA*CD*PSY ANOVA TEST INPUTS

FACTOR	TYPE	LEVELS	VALUES
DA	fixed	2	1 2
CD	fixed	2	1 2
PSY	fixed	2	1 2

Table 12: DA*CD*PSY ANOVA TEST RESULTS

SOURCE	DF	SS	MS	F	P
DA	1	73197	73197	70.80	0.006
CD	1	105657	105657	102.20	0.006
PSY	1	114075	114075	110.34	0.000
DA*CD	1	7788	7788	7.53	0.006
DA*PSY	1	5235	5235	5.06	0.025
CD*PSY	1	1509	1509	1.46	0.228
DA*CD* PSY	1	348	348	0.34	0.562
ERROR	392	405257	1034		
TOTAL	399	713067			

In this variation only two interactions are significant, DA*CD and DA*PSY. Clearly changing the indecisiveness probabilities had some effect as noted by the decreased p-values for DA*CD and DA*CD*PSY to that of the original model. The variation of the indecisiveness probabilities did not have the same effect on the interactions as changing the output probabilities. The relationship between the output probabilities may have been the cause of the interactions in this model; however, this relationship is beyond the scope of this study and will be left to any follow-on research. The final step to this study was to determine the validity of the experiment.

3. Validity of Experiment

The purpose of the model design was to vary the speed factor of the specific mechanism subtypes which would randomly

affect the time required to produce the CJTF Execute Order. If the design were correct, then each subtype (identified as a factor in ANOVA testing) would be significant and the hypothesis of the opposite effect would be rejected. This is the case for this model. Analysis of the experimental data verified the accuracy of the experiment's design.

The design of the model was such that the factors would be additive, as verified by the large values obtained for the TIME column. An unexpected result was discovered even though there was no attempt to build in interactions between the factors. The unexpected result was that of an interaction between DA and PSY, which is considered a synergistic effect. The reason for this is unclear, but it prompted the idea of varying parts of the design to see what would happen.

IV. CONCLUSION

In this study a prototype model for battle damage assessment in C^2 warfare was built. The purpose was to provide an easier avenue for research into the effects of C^2W in an unclassified environment. Commercial off-the-shelf software was used that allowed a study of the dynamic behavior of a JTF information handling system in a hostile environment.

The model worked well in as much as it performed as it was designed to and is of simple construction. It is not as flexible as was hoped for, but that is due to its construction as opposed to any inherent limitation of the software. Research in this area and with this model/software shouldn't stop here. There are several possibilities for follow-on research. One possibility is to generalize the model for force structures other than the JTF. This could prove useful in a wider range of situations. A second area would be to marry the model with simulated (or actual) methods of measuring communications. A different MOE might be discovered or another way to infer the one used in this study. Another possibility would be to assign "true" values to the subtypes used for data attack, C^3 degradation, and psyops. Done in connection with a more detailed breakout of the force's C^3 structure (including performance data on systems and number of personnel for each activity), this could be extremely useful. An extension of this would be to study the cost of C^2W to

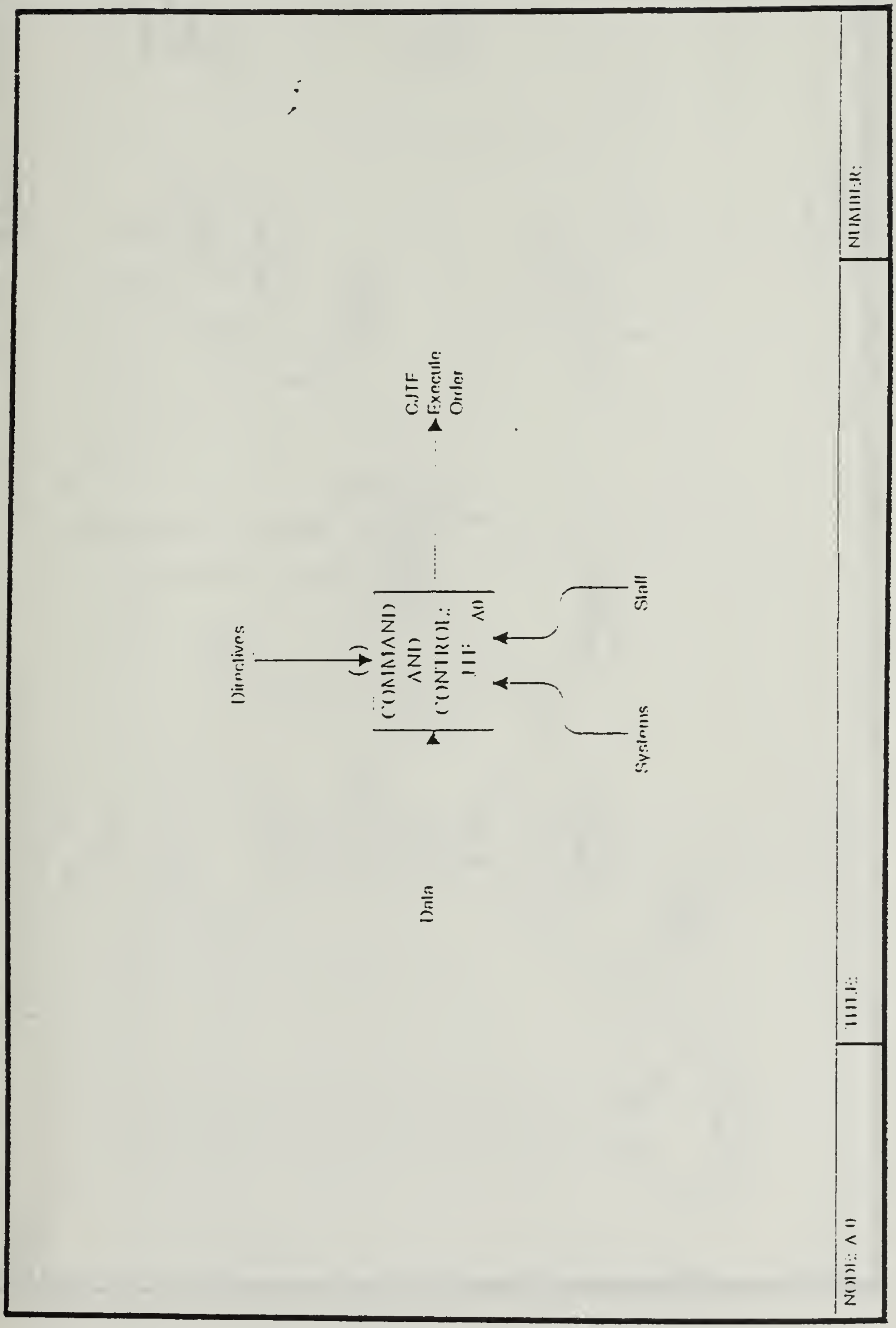
enemy forces or the cost of C^2W defense to friendly forces. A final possibility is to incorporate the model into automated mission planning. This might prove to be very interesting if it can be done.

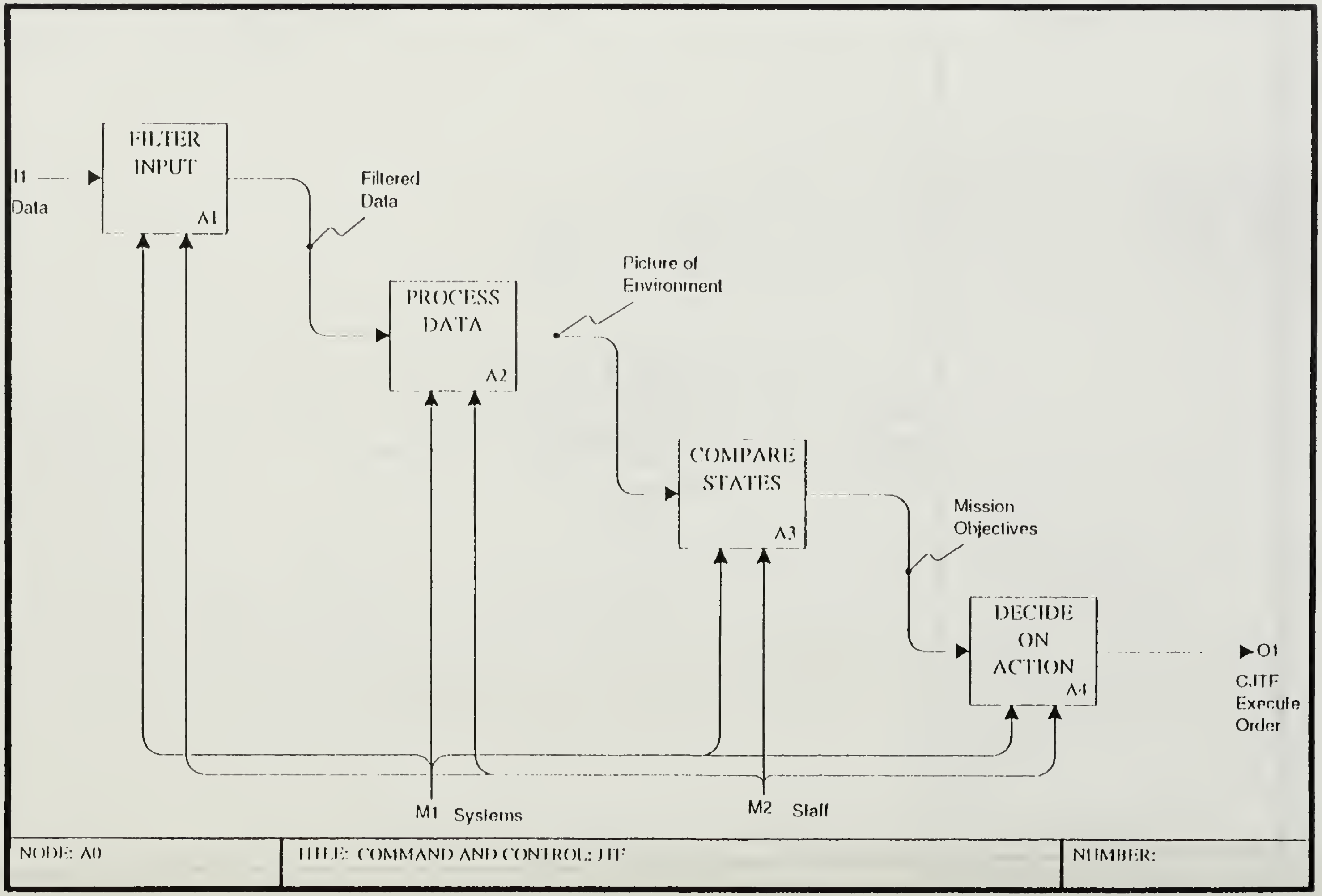
C^2 warfare will only grow in the importance it plays in modern warfighting. Proper preparation requires continued research outside the classified environments where it is usually conducted. This model and its successors can provide the tools for that research.

APPENDIX A - ACTIVITY ASSIGNMENT MATRIX

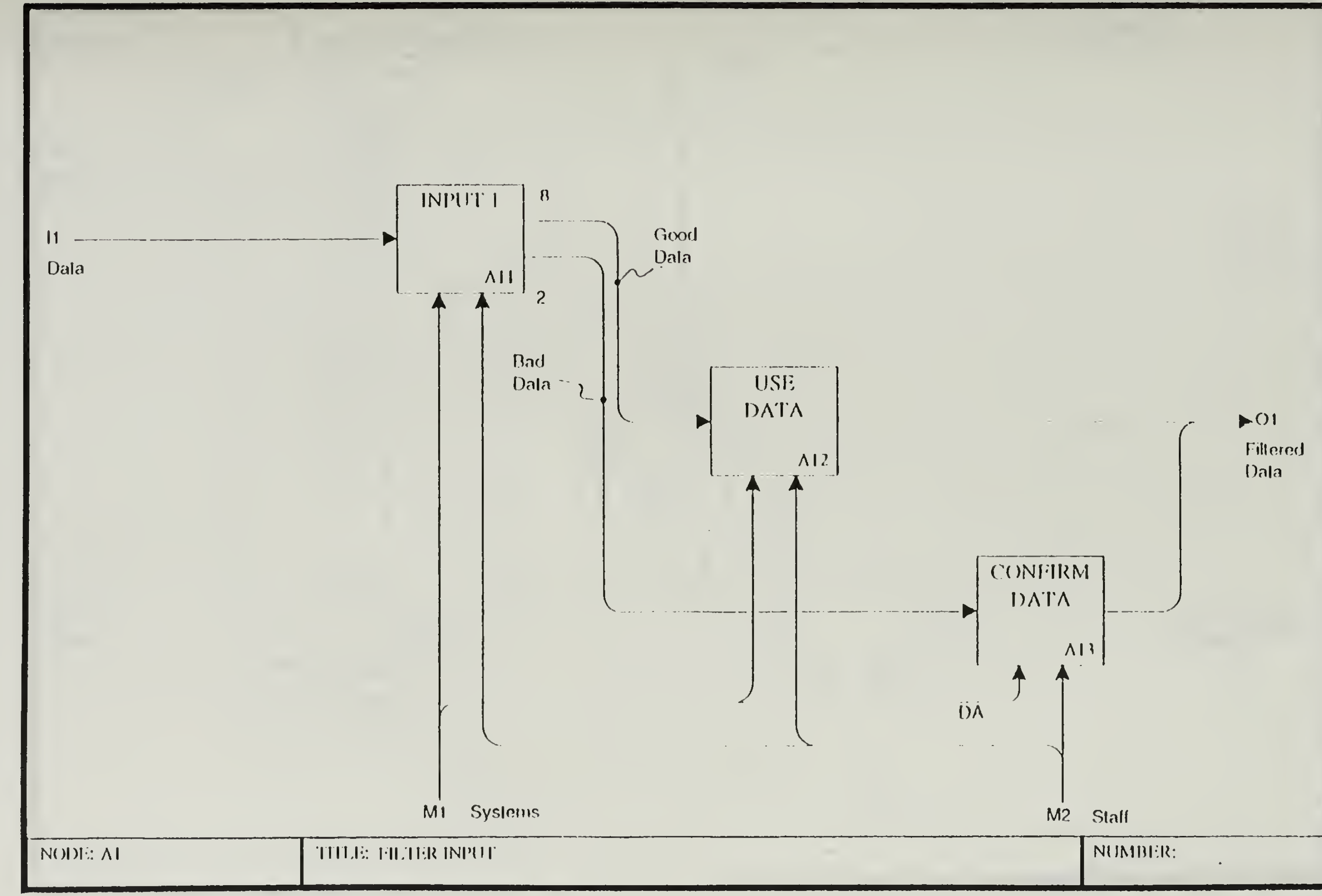
Function	Activities
Process	A111, A112, A113
Compare	A21, A22
Decide	A23, A311, A312, A313, A3211, A3212, A3213, A3214, A3215, A3216, A322, A323, A3311, A3312, A3313, A3314, A3315, A3316, A332, A333, A341, A342, A343, A411, A412, A413, A414, A421, A422, A423, A43,A51

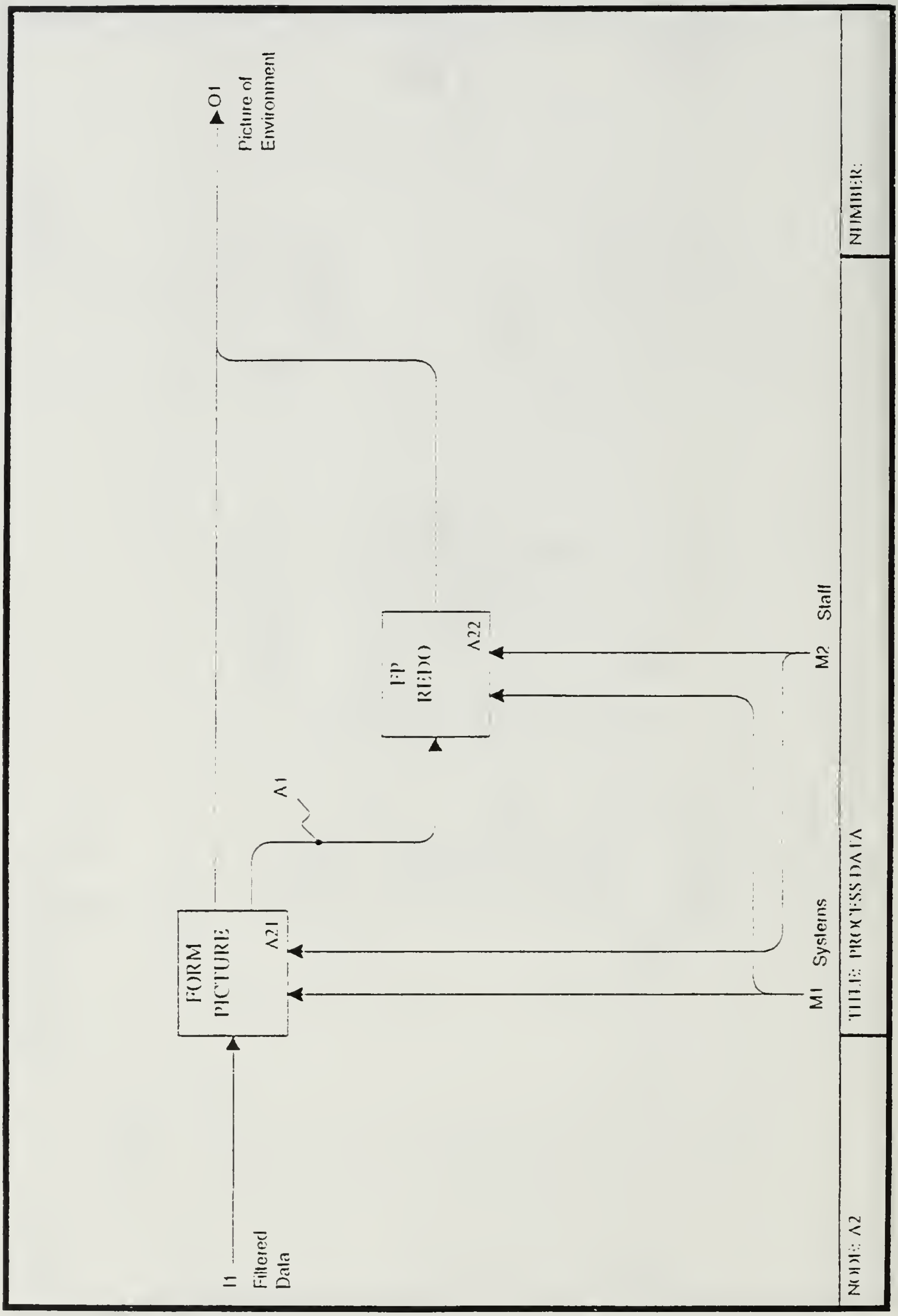
APPENDIX B - IDEF0 MODEL

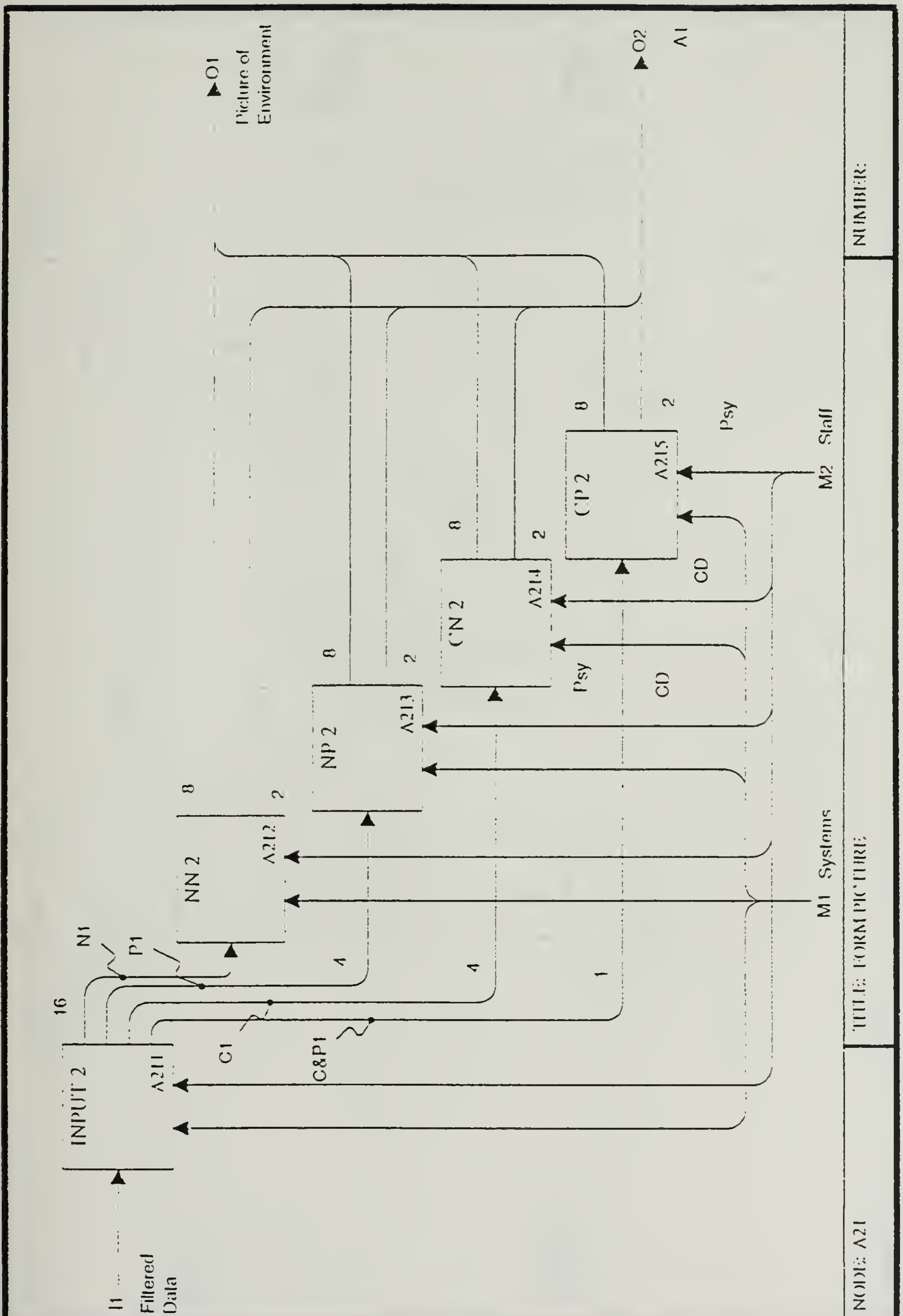


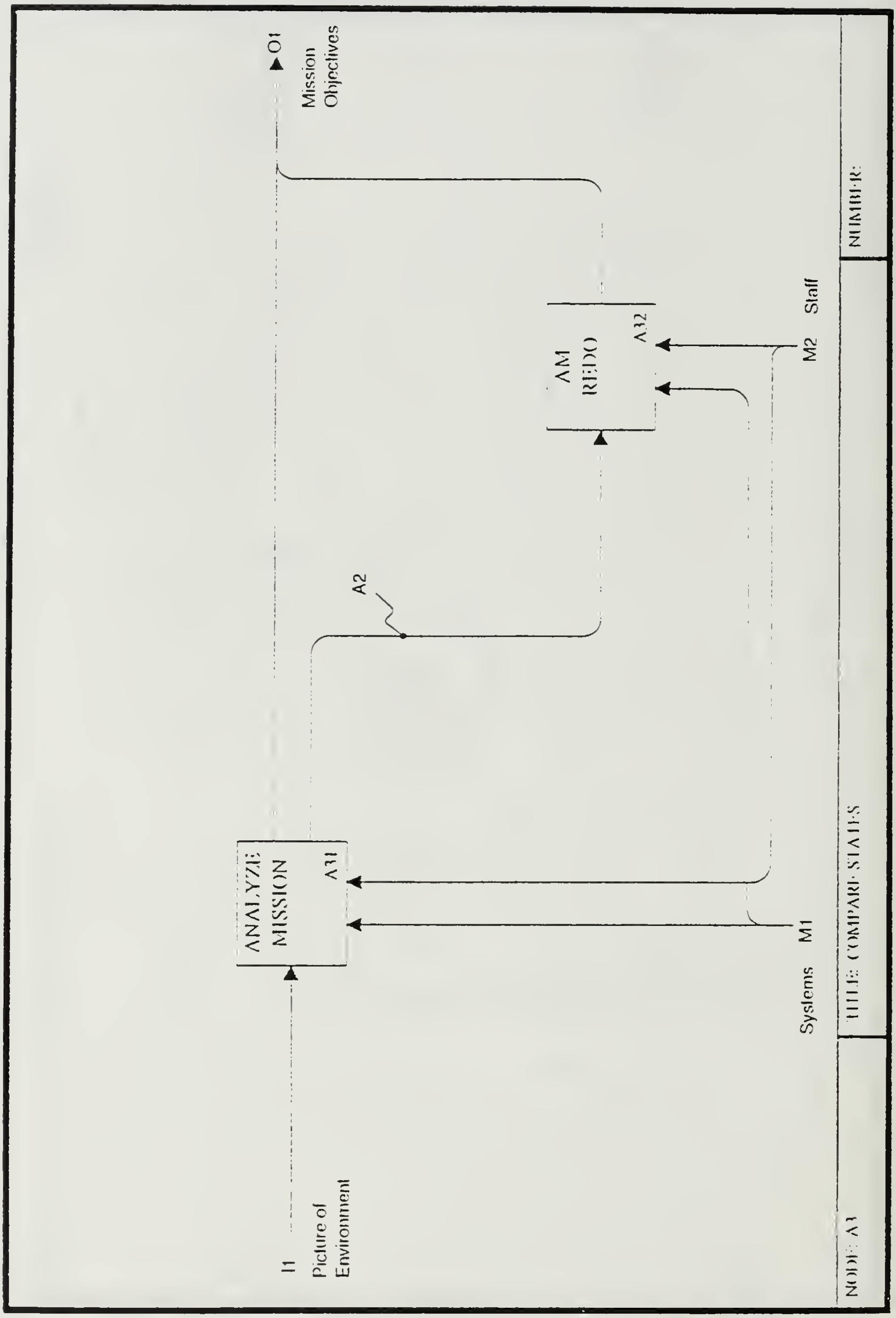


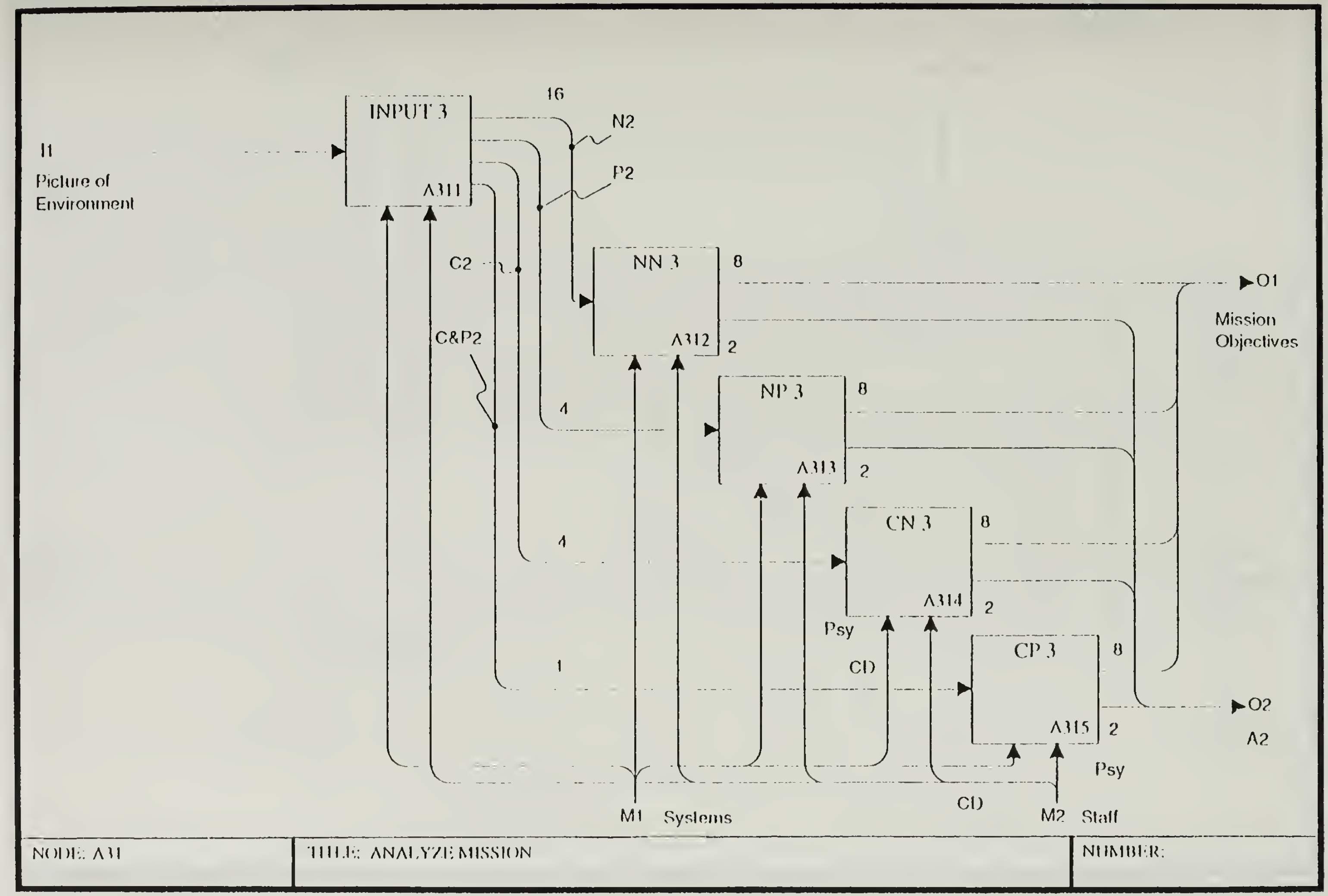
I1
Data
FILTER INPUT
A1
Filtered Data
PROCESS DATA
A2
Picture of Environment
COMPARE STATES
A3
Mission Objectives
DECIDE ON ACTION
A4
O1
CJTF Execute Order
M1 Systems
M2 Staff
NODE: A0
TITLE: COMMAND AND CONTROL: JTF
NUMBER:

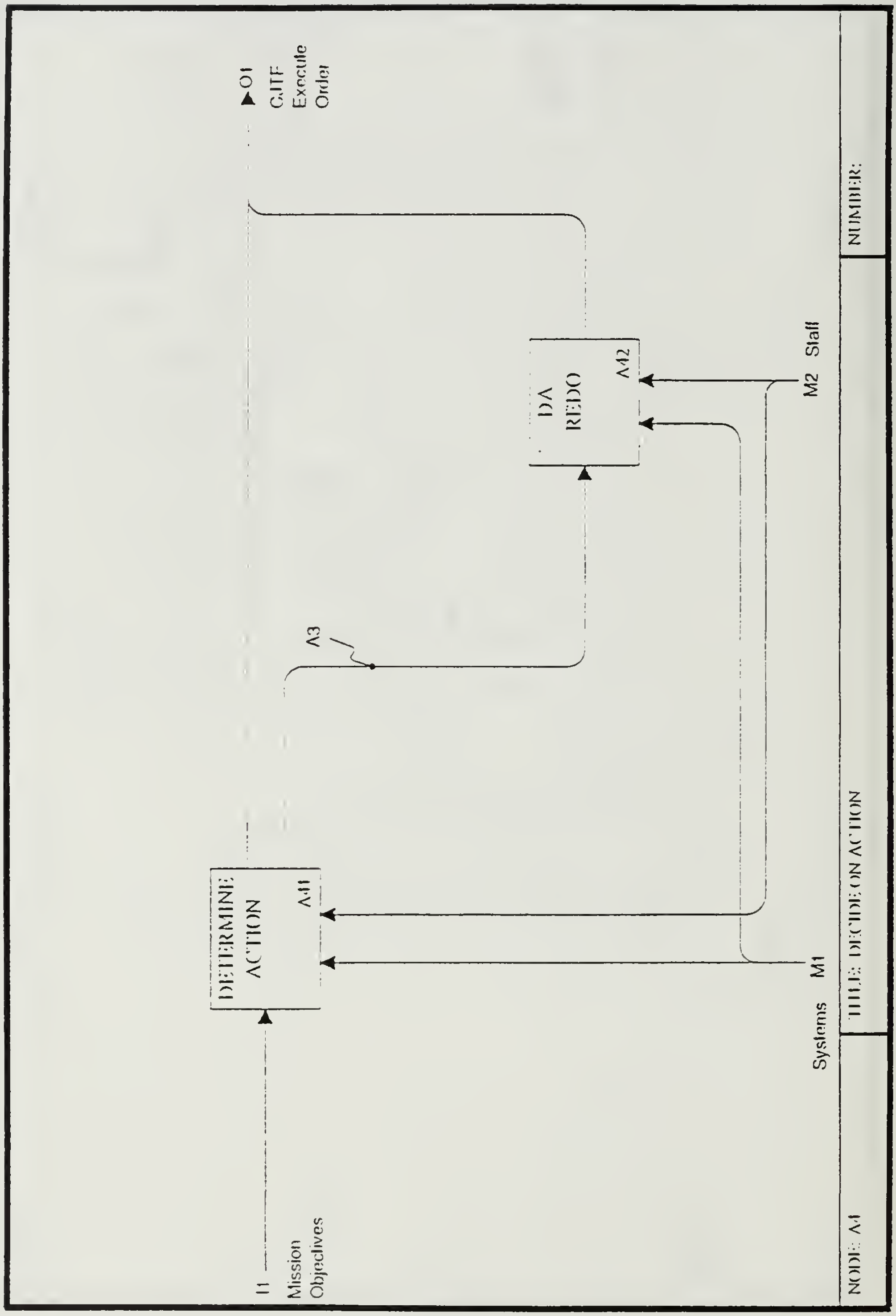

I1
Data
INPUT I
A11
8
2
Good
Data
Bad
Data
USE
DATA
A12
CONFIRM
DATA
A13
DA
O1
Filtered
Data
M1
Systems
M2
Staff
NODE: A1
TITLE: FILTER INPUT
NUMBER:

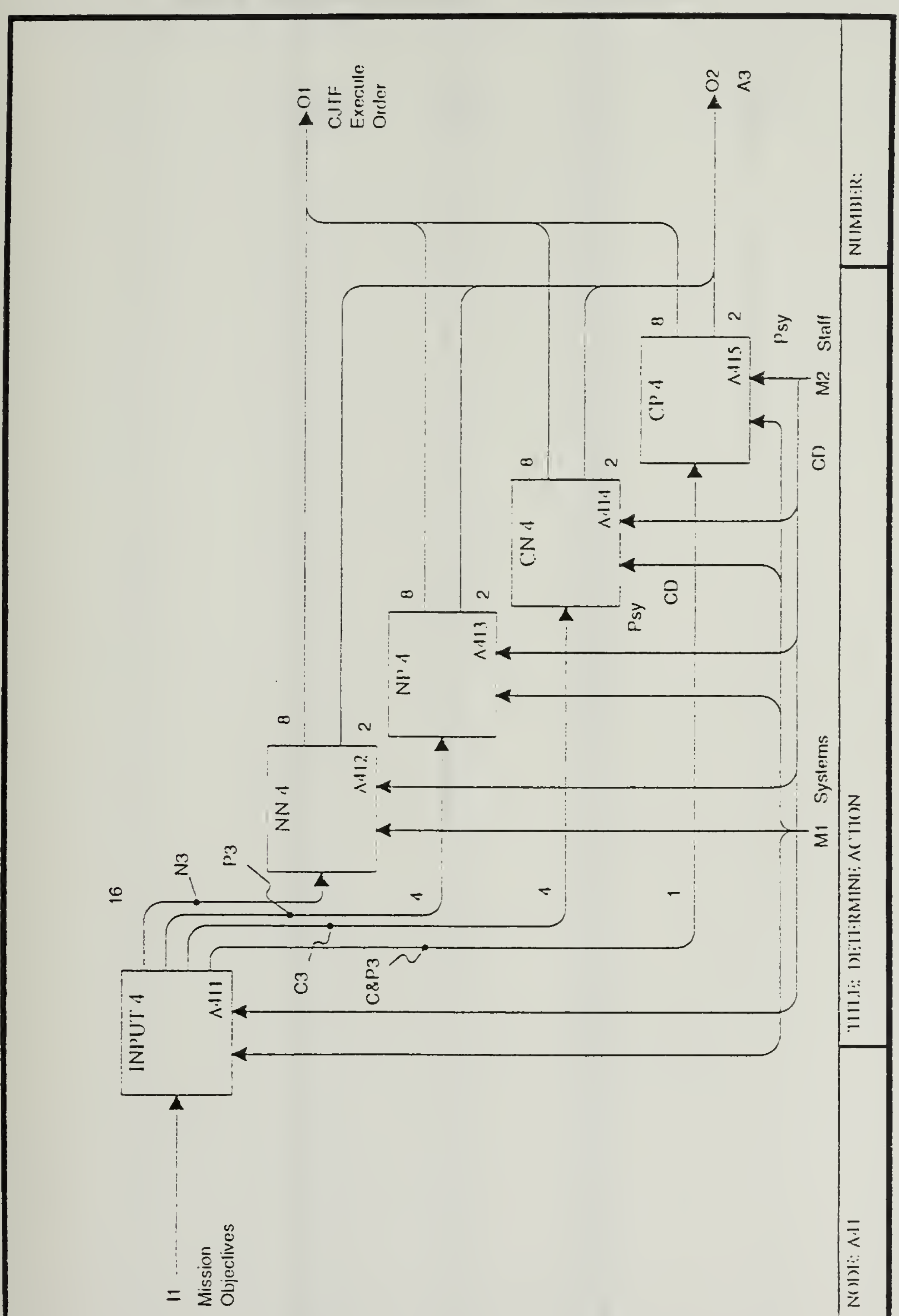

I1
Filtered Data
FORM PICTURE
A21
A1
FP REDO
A22
O1
Picture of Environment
M1 Systems
M2 Staff
NODE: A2
TITLE: PROCESS DATA
NUMBER:


I1 Filtered Data
INPUT 2
A211
16
N1
P1
C1
C&P1
NN 2
A212
8
2
4
4
1
NP 2
A213
8
2
CN 2
A214
8
2
Psy
CD
CP 2
A215
8
2
Psy
CD
M1 Systems
M2 Staff
O1 Picture of Environment
O2
A1
NODE: A21
TITLE: FORM PICTURE
NUMBER:


I1
Picture of Environment
ANALYZE MISSION
A31
A2
AM REDO
A32
O1
Mission Objectives
Systems
M1
M2
Staff
NODE: A3
TITLE: COMPARE STATES
NUMBER:


INPUT 3
A311
I1
Picture of
Environment
16
N2
P2
C2
C&P2
NN 3
A312
8
2
NP 3
A313
8
2
CN 3
A314
8
2
CP 3
A315
8
2
4
4
1
Psy
CD
Psy
CD
O1
Mission
Objectives
O2
A2
M1 Systems
M2 Staff
NODE: A31
TITLE: ANALYZE MISSION
NUMBER:


I1
Mission
Objectives
DETERMINE
ACTION
A41
A3
DA
REDO
A42
O1
CJTF
Execute
Order
M1
Systems
M2
Staff
NODE: A4
TITLE: DECIDE ON ACTION
NUMBER:


I1 Mission Objectives
INPUT 4
A411
NN 4
A412
NP 4
A413
CN 4
A414
CP 4
A415
16
N3
P3
C3
C&P3
4
4
1
8
2
Psy
CD
M1 Systems
M2 Staff
O1 CJTF Execute Order
O2 A3
NODE: A11
TITLE: DETERMINE ACTION
NUMBER:

APPENDIX C - EXPERIMENTAL DATA

	C1 DA	C2 CD	C3 PSY	C4 TIME
1	1	1	1	45
2	1	1	1	82
3	1	1	1	52
4	1	1	1	45
5	1	1	1	80
6	1	1	1	45
7	1	1	1	45
8	1	1	1	50
9	1	1	1	48
10	1	1	1	45
11	1	1	1	47
12	1	1	1	83
13	1	1	1	82
14	1	1	1	50
15	1	1	1	45
16	1	1	1	80
17	1	1	1	83
18	1	1	1	83
19	1	1	1	50
20	1	1	1	50
21	1	1	1	85
22	1	1	1	80
23	1	1	1	45
24	1	1	1	45
25	1	1	1	47
26	1	1	1	52
27	1	1	1	45
28	1	1	1	90
29	1	1	1	48
30	1	1	1	53
31	1	1	1	48
32	1	1	1	50
33	1	1	1	47
34	1	1	1	50
35	1	1	1	45
36	1	1	1	45
37	1	1	1	45
38	1	1	1	45
39	1	1	1	80
40	1	1	1	50
41	1	1	1	80
42	1	1	1	53
43	1	1	1	82
44	1	1	1	45

45	1	1	1	85
46	1	1	1	50
47	1	1	1	50
48	1	1	1	45
49	1	1	1	45
50	1	1	1	85
51	2	1	1	47
52	2	1	1	52
53	2	1	1	97
54	2	1	1	130
55	2	1	1	81
56	2	1	1	56
57	2	1	1	48
58	2	1	1	59
59	2	1	1	86
60	2	1	1	50
61	2	1	1	86
62	2	1	1	48
63	2	1	1	117
64	2	1	1	81
65	2	1	1	48
66	2	1	1	94
67	2	1	1	122
68	2	1	1	47
69	2	1	1	84
70	2	1	1	97
71	2	1	1	104
72	2	1	1	45
73	2	1	1	117
74	2	1	1	80
75	2	1	1	94
76	2	1	1	45
77	2	1	1	83
78	2	1	1	97
79	2	1	1	58
80	2	1	1	55
81	2	1	1	61
82	2	1	1	51
83	2	1	1	48
84	2	1	1	45
85	2	1	1	125
86	2	1	1	94
87	2	1	1	50
88	2	1	1	57
89	2	1	1	83
90	2	1	1	133
91	2	1	1	98
92	2	1	1	58
93	2	1	1	45
94	2	1	1	61
95	2	1	1	93
96	2	1	1	63

97	2	1	1	87
98	2	1	1	63
99	2	1	1	51
100	2	1	1	48
101	1	2	1	45
102	1	2	1	45
103	1	2	1	45
104	1	2	1	55
105	1	2	1	55
106	1	2	1	45
107	1	2	1	48
108	1	2	1	85
109	1	2	1	48
110	1	2	1	50
111	1	2	1	45
112	1	2	1	85
113	1	2	1	85
114	1	2	1	48
115	1	2	1	45
116	1	2	1	50
117	1	2	1	45
118	1	2	1	47
119	1	2	1	83
120	1	2	1	45
121	1	2	1	50
122	1	2	1	45
123	1	2	1	55
124	1	2	1	47
125	1	2	1	50
126	1	2	1	82
127	1	2	1	45
128	1	2	1	45
129	1	2	1	45
130	1	2	1	50
131	1	2	1	45
132	1	2	1	50
133	1	2	1	80
134	1	2	1	52
135	1	2	1	45
136	1	2	1	45
137	1	2	1	50
138	1	2	1	45
139	1	2	1	50
140	1	2	1	45
141	1	2	1	45
142	1	2	1	83
143	1	2	1	47
144	1	2	1	52
145	1	2	1	50
146	1	2	1	45
147	1	2	1	83
148	1	2	1	45

149	1	2	1	53
150	1	2	1	83
151	1	1	2	120
152	1	1	2	49
153	1	1	2	81
154	1	1	2	47
155	1	1	2	88
156	1	1	2	102
157	1	1	2	81
158	1	1	2	50
159	1	1	2	134
160	1	1	2	97
161	1	1	2	115
162	1	1	2	84
163	1	1	2	84
164	1	1	2	86
165	1	1	2	86
166	1	1	2	87
167	1	1	2	94
168	1	1	2	83
169	1	1	2	124
170	1	1	2	125
171	1	1	2	85
172	1	1	2	63
173	1	1	2	129
174	1	1	2	83
175	1	1	2	52
176	1	1	2	57
177	1	1	2	99
178	1	1	2	87
179	1	1	2	94
180	1	1	2	80
181	1	1	2	85
182	1	1	2	95
183	1	1	2	49
184	1	1	2	49
185	1	1	2	90
186	1	1	2	81
187	1	1	2	53
188	1	1	2	48
189	1	1	2	99
190	1	1	2	122
191	1	1	2	85
192	1	1	2	87
193	1	1	2	120
194	1	1	2	57
195	1	1	2	45
196	1	1	2	120
197	1	1	2	119
198	1	1	2	115
199	1	1	2	49
200	1	1	2	52

201	2	2	1	88
202	2	2	1	90
203	2	2	1	89
204	2	2	1	169
205	2	2	1	93
206	2	2	1	90
207	2	2	1	92
208	2	2	1	160
209	2	2	1	159
210	2	2	1	89
211	2	2	1	170
212	2	2	1	100
213	2	2	1	90
214	2	2	1	94
215	2	2	1	90
216	2	2	1	90
217	2	2	1	90
218	2	2	1	100
219	2	2	1	100
220	2	2	1	170
221	2	2	1	94
222	2	2	1	94
223	2	2	1	100
224	2	2	1	100
225	2	2	1	160
226	2	2	1	100
227	2	2	1	90
228	2	2	1	100
229	2	2	1	90
230	2	2	1	94
231	2	2	1	100
232	2	2	1	160
233	2	2	1	106
234	2	2	1	90
235	2	2	1	96
236	2	2	1	90
237	2	2	1	106
238	2	2	1	160
239	2	2	1	160
240	2	2	1	170
241	2	2	1	89
242	2	2	1	163
243	2	2	1	95
244	2	2	1	105
245	2	2	1	90
246	2	2	1	94
247	2	2	1	87
248	2	2	1	100
249	2	2	1	89
250	2	2	1	99
251	2	1	2	100
252	2	1	2	160

253	2	1	2	90
254	2	1	2	105
255	2	1	2	90
256	2	1	2	94
257	2	1	2	104
258	2	1	2	94
259	2	1	2	100
260	2	1	2	100
261	2	1	2	89
262	2	1	2	83
263	2	1	2	48
264	2	1	2	83
265	2	1	2	80
266	2	1	2	152
267	2	1	2	88
268	2	1	2	305
269	2	1	2	91
270	2	1	2	194
271	2	1	2	96
272	2	1	2	104
273	2	1	2	106
274	2	1	2	100
275	2	1	2	90
276	2	1	2	166
277	2	1	2	160
278	2	1	2	90
279	2	1	2	90
280	2	1	2	94
281	2	1	2	100
282	2	1	2	160
283	2	1	2	106
284	2	1	2	104
285	2	1	2	90
286	2	1	2	90
287	2	1	2	106
288	2	1	2	164
289	2	1	2	170
290	2	1	2	94
291	2	1	2	90
292	2	1	2	170
293	2	1	2	170
294	2	1	2	96
295	2	1	2	90
296	2	1	2	100
297	2	1	2	90
298	2	1	2	94
299	2	1	2	166
300	2	1	2	90
301	1	2	2	161
302	1	2	2	66
303	1	2	2	190
304	1	2	2	168

305	1	2	2	45
306	1	2	2	165
307	1	2	2	76
308	1	2	2	71
309	1	2	2	191
310	1	2	2	159
311	1	2	2	159
312	1	2	2	89
313	1	2	2	96
314	1	2	2	100
315	1	2	2	93
316	1	2	2	89
317	1	2	2	90
318	1	2	2	162
319	1	2	2	164
320	1	2	2	158
321	1	2	2	90
322	1	2	2	160
323	1	2	2	100
324	1	2	2	90
325	1	2	2	176
326	1	2	2	170
327	1	2	2	94
328	1	2	2	100
329	1	2	2	90
330	1	2	2	173
331	1	2	2	111
332	1	2	2	166
333	1	2	2	67
334	1	2	2	94
335	1	2	2	90
336	1	2	2	199
337	1	2	2	160
338	1	2	2	174
339	1	2	2	90
340	1	2	2	206
341	1	2	2	197
342	1	2	2	95
343	1	2	2	180
344	1	2	2	67
345	1	2	2	159
346	1	2	2	159
347	1	2	2	191
348	1	2	2	207
349	1	2	2	61
350	1	2	2	201
351	2	2	2	330
352	2	2	2	164
353	2	2	2	182
354	2	2	2	172
355	2	2	2	192
356	2	2	2	300

357	2	2	2	164
358	2	2	2	168
359	2	2	2	90
360	2	2	2	180
361	2	2	2	180
362	2	2	2	172
363	2	2	2	98
364	2	2	2	172
365	2	2	2	182
366	2	2	2	176
367	2	2	2	114
368	2	2	2	184
369	2	2	2	232
370	2	2	2	114
371	2	2	2	196
372	2	2	2	90
373	2	2	2	182
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